THE "SUPER-HALO" OF M31 AND M33

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RESUMEN

Favor de proporcionar un resumen en español. If you cannot provide a spanish abstract, the editors will do this. Two recent observations regarding the halo of M33 seem to contradict each other. First, the star clusters in the halo of M33 exhibit an age range of 5 to 7 Gyr suggesting a formation scenario that involves the chaotic fragmentation and accretion of dwarf satellites. In contrast, deep photometric searches for the resultant tidal tails and stellar streams in the vicinity of M33 have turned up nothing significant. In this contribution, we have tried to reconcile these apparently disparate observations. We suggest that M33 is situated within a 'superhalo' which contains many other dwarf spheroidal and dwarf irregular galaxies that are satellites of M31. In such a scenario, the tidal field of M31 could have disrupted and/or diluted the leftover tails and streams leaving little to be detected in the present day.

ABSTRACT

Two recent observations regarding the halo of M33 seem to contradict each other. First, the star clusters in the halo of M33 exhibit an age range of 5 to 7 Gyr suggesting a formation scenario that involves the chaotic fragmentation and accretion of dwarf satellites. In contrast, deep photometric searches for the resultant tidal tails and stellar streams in the vicinity of M33 have turned up nothing significant. In this contribution, we have tried to reconcile these apparently disparate observations. We suggest that M33 is situated within a 'superhalo' which contains many other dwarf spheroidal and dwarf irregular galaxies that are satellites of M31. In such a scenario, the tidal field of M31 could have disrupted and/or diluted the leftover tails and streams leaving little to be detected in the present day.

Key Words: **GALAXIES: DWARF — GALAXIES: SPIRAL — GALAXIES: STRUCTURE — GALAXIES: FORMATION**

1. INTRODUCTION

The Local Group of galaxies is an excellent laboratory within which to conduct detailed studies of how galaxies form and evolve. One reason for this is that the galaxies are all close enough to make in-depth studies of their stellar populations feasible. Another reason is that the Local Group contains examples of all major galaxy morphology classes - including spirals, ellipticals, dwarf irregulars, and dwarf spheroidals. There is enough diversity in the Local Group so that studies of the detailed properties of its galaxies hold great promise in unlocking the secrets of star and galaxy formation in a variety of different environments. In addition, the Local Group is also a window into the general process of structure formation in the early Universe and the relevance of cold dark matter models in describing this process (e.g. Font et al. 2006, and references therein).

In this contribution, we focus on two spiral galaxies of the Local Group - M31 and M33. At a distance of ∼800 kpc, the M31 system includes over a dozen dwarf galaxies, including M33, which is a member of the class of *dwarf spirals*. It is approximately one magnitude brighter than the Large Magellanic Cloud. Studies have shown that M33 possesses kinematically distinct disk and halo populations (Schommer et al. 1991; Chandar et al. 2002). The halo of M33 is particularly intriguing because its member star clusters exhibit an age range of between 5 and 7 Gyr (Sarajedini et al. 1998, 2000; Chandar et al. 2002). While the spatial extent of the M33 disk and halo is still largely unknown, wide-field photometric surveys of M33 do not show any traces of tidal tails or streams in its halo (Fig. 3 of McConnachie et al. 2004), unlike the Milky Way (Ibata, Gilmore, & Irwin 1994; Majewski et al. 2006) and M31 (Ferguson et al. 2002; Guhathakurta et al. 2006), which exhibit extensive substructure in their halos. It should be noted however that in their kinematical study of a small region along the major axis of M33, McConnachie et al. (2006) detect a minor velocity component that is neither coincident with the disk nor

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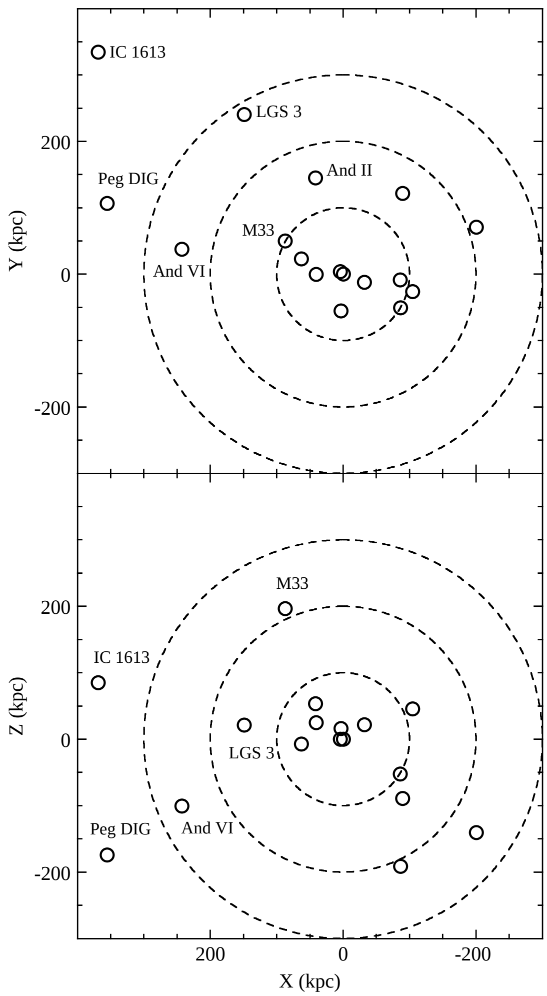

Fig. 1. The distribution of M31 dwarf galaxies and M33 in the X-Y-Z plane defined with M31 at its center using data in Table 1 of Koch & Grebel (2006). The concentric circles represent 100 kpc radii.

the halo, and which they suggest could be a tidal tail or stream. The significant age range of the M33 halo clusters (5-7 Gyr) suggests a formation scenario for the M33 halo which involves the fragmentation and accretion of subgalaxy fragments. This is at odds with the finding that the remnants of such objects are largely missing today in the M33 halo. This apparent contradiction can be better understood if we examine M33 as a member of the M31/M33 superhalo.

2. M31 AND M33 SUPER-HALO

The M31 system of dwarf galaxies includes such notable members as M32, NGC 205, NGC 185, NGC 147, and a number of dwarf spheroidal and dwarf irregular galaxies. It also includes the dwarf spiral galaxy M33. Figure 1 shows the X-Y-Z locations of galaxies in the superhalo of M31 centered on M31. These data are taken from Table 1 of Koch & Grebel (2006). The dashed circles represent radii at 100 kpc intervals. Figure 1 shows that M33 is relatively isolated at a distance of ~220 kpc from M31 in 3-D space.

Figure 2 shows the radial velocities of galaxies in the M31 superhalo taken from the NASA Extragalactic Database as a function of radial distance in the disk of M31. These are the same galaxies that are plotted in Fig. 1. Figure 2 illustrates the fact that the members of the superhalo are not rotating so that kinematically, they represent a 'hot' population. Note that the point located at the origin is M31.

We now turn to a discussion of Fig. 3 which plots the metallicities of various superhalo constituents as a function of their distance from M31. The three open circles between 10 and 100 kpc are the fields observed by Kalirai et al. (2006) from their Table 3. The inner point is bulge-dominated, the outer point is halo dominated, while the middle point is some mix of bulge and halo. These fields are located to the southeast of M31 in the direction of M33 on the sky. The open circle at 1.6 kpc represents the putative M31 bulge from the work of Sarajedini & Jablonka (2005). The dashed line is the least squares fit to the four open circles. The filled circles are the dwarf galaxies in Table 1 of Koch & Grebel (2006) supplemented by the metallicities given in Table 1 of Grebel, Gallagher, & Harbeck (2003). The metallicity dispersions in Table 1 of Grebel et al. (2003) have been divided in half to simulate 1-σ errors. We also include the location of And IX published in the work of Harbeck et al. (2005). These metallicities are on an internally consistent scale and have been estimated via photometric and spectroscopic methods (Grebel et al. 2003). The squares represent three globular clusters in M31 - B327 and G1 (Koch & Grebel 2006, open squares) and the furthest known globular cluster from the center of M31 discovered by Martin et al. (2006, filled square). Lastly, the rectangular region is the location and metallicity range of halo clusters in M33 based on the work of Sarajedini et al. (1998; 2000).

3. DISCUSSION

It is interesting to note that the dashed line in Fig. 3 fitted to the open circles in M31 also intersects the low metallicity regime of the *M33 halo clusters*. The globular cluster G1 and the most distant M31 globular are also consistent with this line. The globular cluster B327 and the dwarf elliptical galaxy M32 are far from the dashed line, which could be because their current positions (close to the center of M31) are not representative of their apogalactic locations (i.e. their formation locations). With the possible exception of And IX, the dwarf spheroidals and irregulars also cluster around this line but whether they actually follow the dashed line is an open question.

Focusing now on the location of M33 in Fig. 3, one could argue that because the metal-poor tail of the halo globular clusters in M33 is consistent with the "bulge" metallicity gradient of M31, that the former is actually a constituent of the latter. On the other hand, one could also claim that because the entire range of halo metallicities in M33 is within the range of the M31 dwarf spheroidals and irregulars, then the halo of M33 is a constituent of the M31 halo not its "bulge." In either case, Fig. 3 suggests that M31 and M33 reside in a superhalo that also contains at least 15 other galaxies of various types.

This concept of a superhalo containing M31 and M33 along with other galaxies can potentially explain the apparent contradiction presented in the Introduction. On the one hand, there is a significant age range among the halo star clusters in M33 suggesting that a process akin to fragmentation and accretion formed the M33 halo. If so, then we should see traces of tidal tails and streams that represent the 'leftovers' of this process. On the other hand, surveys to search for these signatures (at the same surface brightness levels as those in M31) have revealed nothing significant (e.g. McConnachie et al. 2004). This indicates that the streams could be below the surface brightness detection limits of the surveys, which can happen if the tidal field of the superhalo has disrupted and/or diluted the streams. In addition, this suggests that streams located in another part of the superhalo could have originated as dwarf galaxies in the vicinity of M33. The properties of such a stream such as metallicity and age would be more similar to those of M33 than M31. All of these speculations depend on the strength of the M31 tidal field at the location of M33, which is a highly uncertain quantity. Not only are the relative masses of M31 and M33 uncertain, but the relative positions of M31 and M33 in space when the bulk of the tidal stream destruction was occurring is also uncertain.

4. SUMMARY AND CONCLUSIONS

In this short contribution, we have tried to reconcile the significant age range among M33 halo clusters which argues in favor of halo formation via fragmentation/accretion of dwarf satellites and the lack of detectable tidal streams in the vicinity of M33 that would be leftover from such a process. We show that M33 is situated within a 'superhalo' which contains many other dwarf spheroidal and dwarf irregular galaxies that are satellites of M31. We suggest that, because M33 is within the superhalo of M31, the tidal field of the latter has successfully disrupted and/or diluted the leftover tails and streams thereby rendering them undetectable by imaging surveys that have found similar structures near M31.

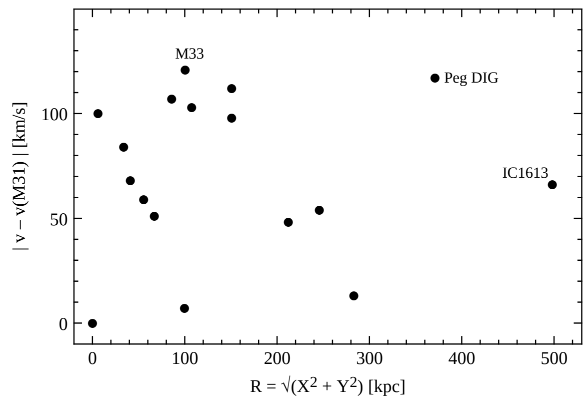

Fig. 2. The distribution of radial velocities relative to M31 for the M31 dwarf galaxies and M33. The positional data are taken from Table 1 of Koch & Grebel (2006) while the velocities are from the NASA Extragalactic Database.

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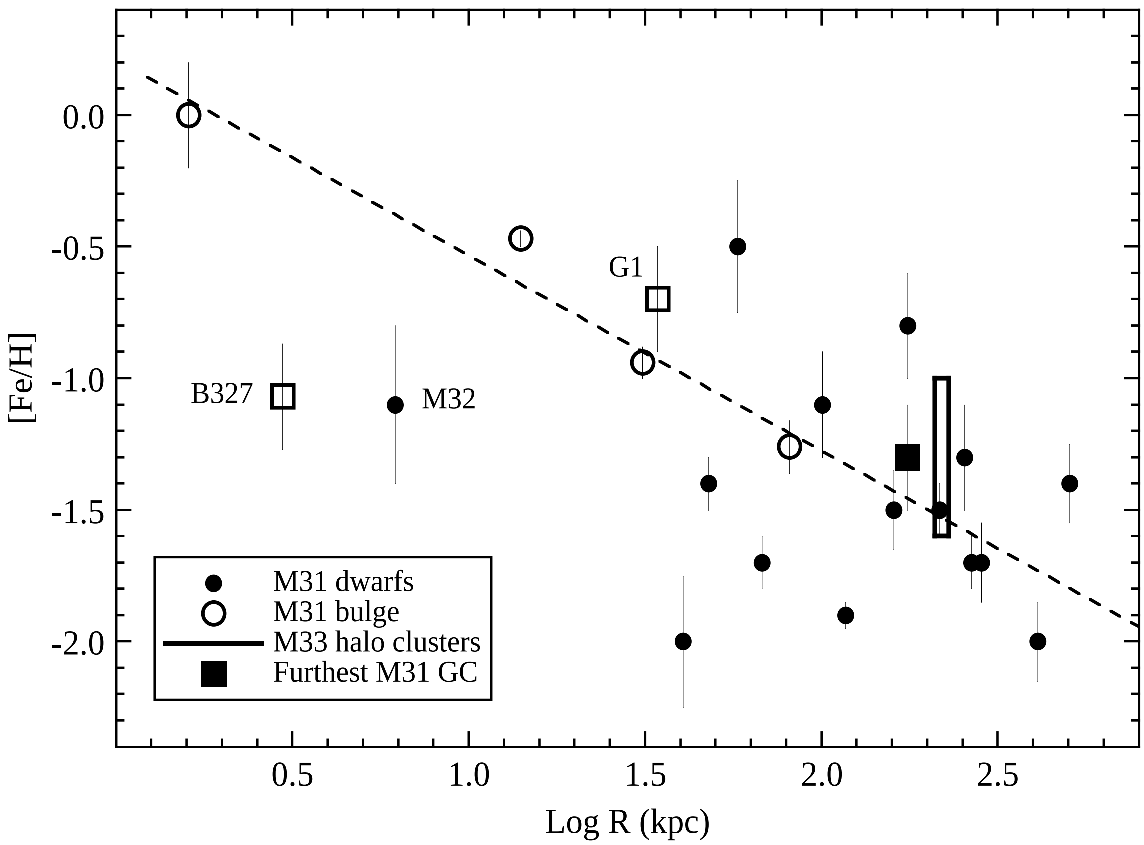

Fig. 3. The radial metallicity gradient in the super-halo of M31. The open circles between 10 and 100 kpc are taken from Kalirai et al. (2006) while the one representing the putative bulge population is from Sarajedini & Jablonka (2005). The dashed line is the least squares fit to these data. The filled circles are the dwarf galaxies in Table 1 of Koch & Grebel (2006) supplemented by the metallicities given in Table 1 of Grebel, Gallagher, & Harbeck (2003). We also include the location of And IX (Harbeck et al. 2005). The squares are three globular clusters in M31 (Koch & Grebel 2006, open squares; Martin et al. (2006, filled square). The rectangular region is the location and metallicity range of halo clusters in M33 based on the work of Sarajedini et al. (1998; 2000).

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